ABSTRACT:

Title: The sub-parsec structure of accretion disks as revealed by VLBI imaging of free-free absorption

The physical conditions in the inner parsec of accretion disks believed to orbit the central black holes in active galactic nuclei can be probed by imaging the absorption of background radio emission by ionized gas in the disk. High angular resolution radio observations of several nearby galaxies at multiple frequencies has revealed evidence for free-free absorption by disks or tori of ionized gas. The depth and angular width of the absorption appears to increase with decreasing frequency, as expected. Because free-free absorption is much larger at lower frequencies, the longest possible baselines are needed to provide adequate angular resolution; observing at higher frequencies to improve resolution will not help in general. Recent results from VSOP as well as ground-based VLBI arrays will be presented, and constraints on the structure of absorbing material will be discussed.

THE SUB-PARSEC STRUCTURE OF ACCRETION DISKS AS REVEALED BY VLBI IMAGING OF FREE-FREE ABSORPTION

D. L. Jones, A. E. Wehrle, B. G. Piner, & D. L. Meier

Jet Propulsion Laboratory,
California Institute of Technology

IAU Symposium 205

August 2000

Summary

We derive the physical characteristics of the accretion disk within one parsec of the central supermassive black hole in the nearby FR-I galaxy NGC 4261. The disk absorbs synchrotron radiation from the base of the relativistic jets through free-free absorption. Multifrequency VLBA data yield the accretion disk thickness, diameter, electron density, and magnetic field.

Introduction

The structure of AGN accretion disks on sub-parsec scales can be probed through free-free absorption of synchrotron emission from the base of symmetric radio jets. For objects in which both jet and counterjet are detectable with VLBI, the accretion disk will cover part of the counterjet and produce

diminished brightness whose angular size and depth as a function of frequency can reveal the radial distribution of free electrons in the disk. The nearby (41 Mpc) FR-I radio galaxy NGC 4261 contains a pair of symmetric kpc-scale jets. On parsec scales, radio emission from the nucleus is strong enough for detailed imaging with VLBI.

Observations

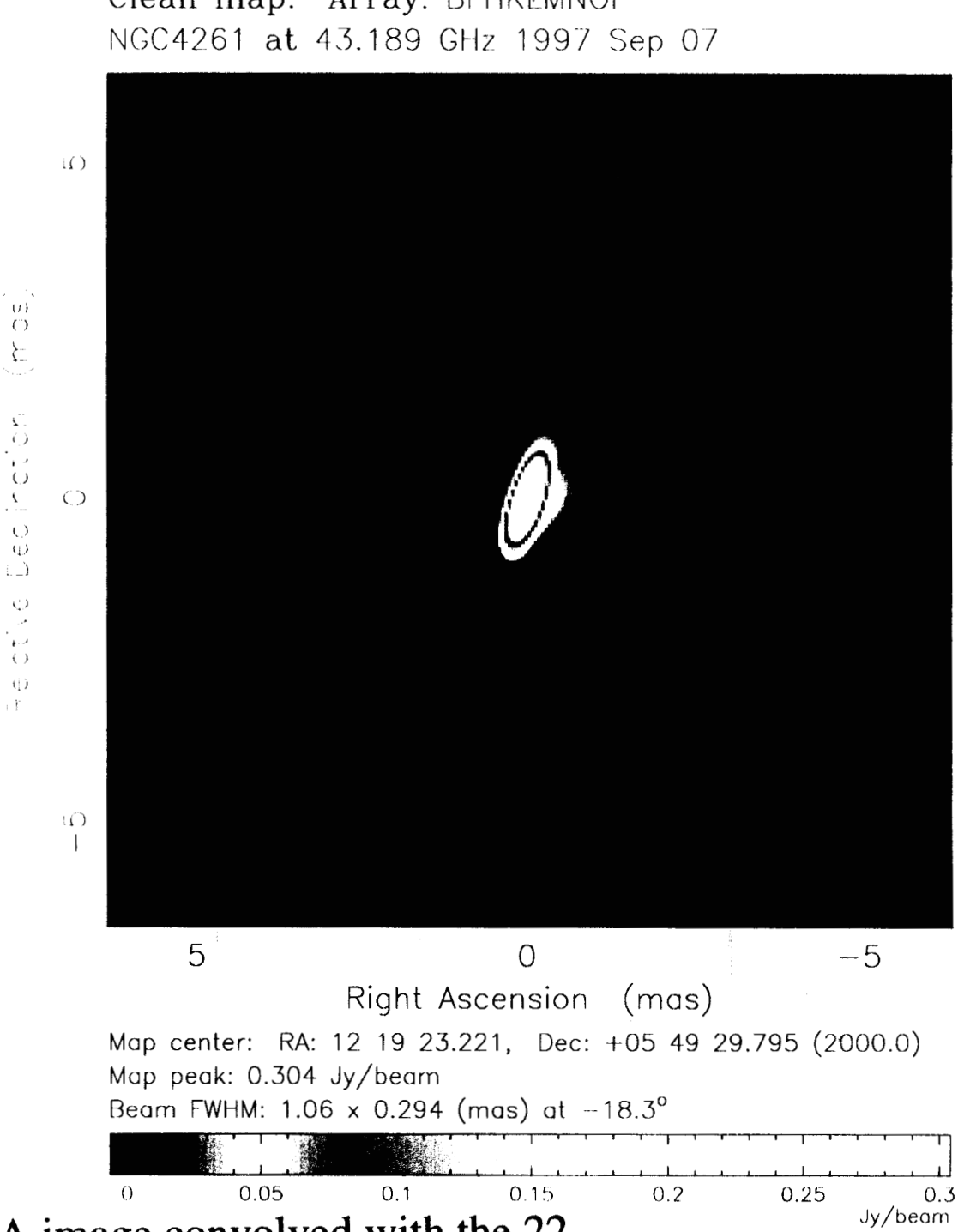
We present new VLBA observations of NGC 4261 at 22 and 43 GHz, which we combine with previous observations at 1.6 and 8.4 GHz to map the absorption caused by an inner accretion disk. The relative closeness of NGC 4261 combined with the high angular resolution provided by the VLBA at 43 GHz gives us a very high resolution, approximately 0.1 mas or 0.02 parsecs or 4000 AU or 400 Schwarzschild radii for a 5×10^8 solar mass black hole.

Appearance of the Jets

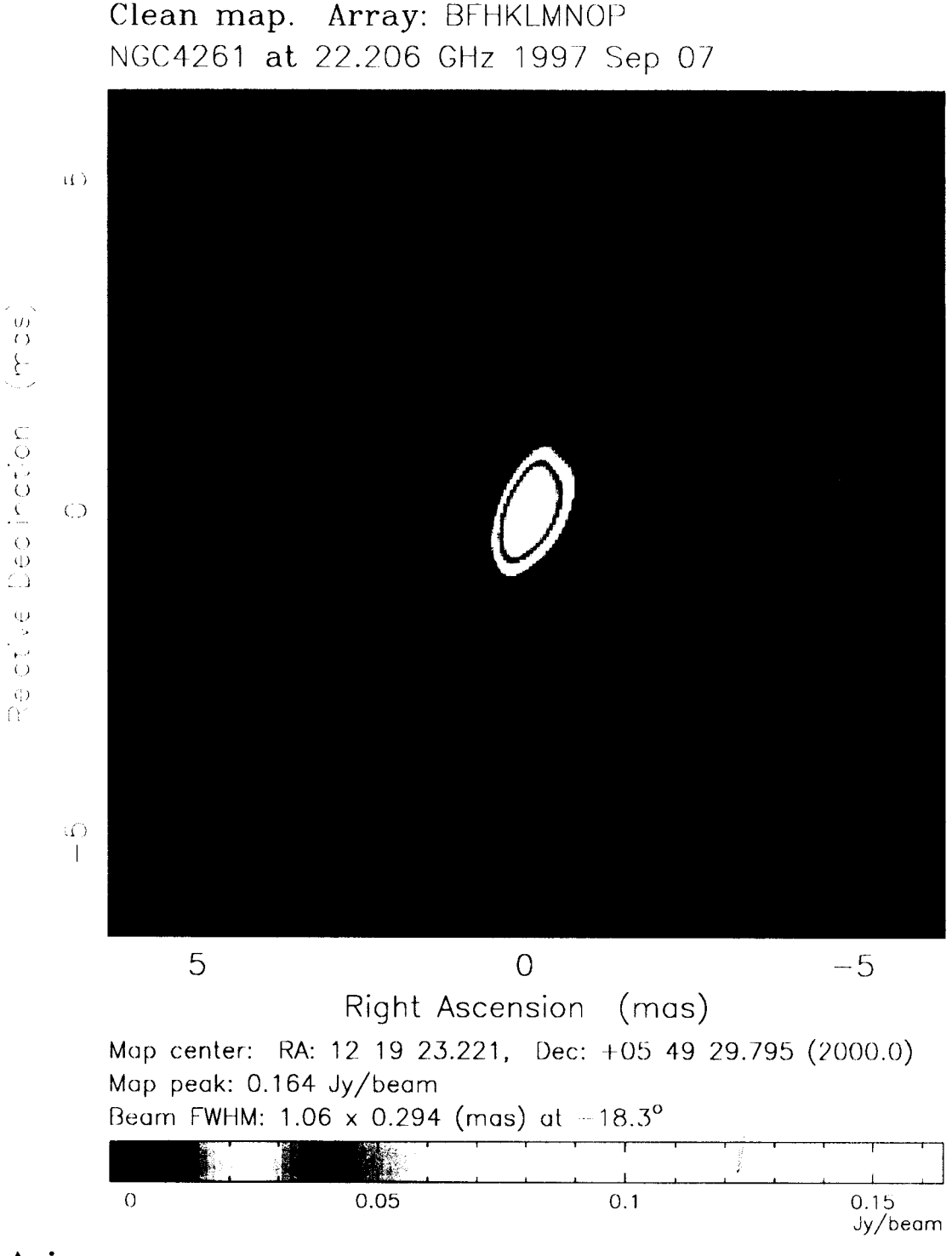
The jets appear more symmetric at 1.6 GHz because of the low resolution available. The jets are also more symmetric at 22 and 43 GHz, presumably because the optical depth of free-free absorption is small at high

frequencies. At 8.4 GHz, neither confusion effect is dominant, and absorption of the counterjet emission by the presumed disk is detectable. We find that the orientation of the radio jet axis is the same on parsec and kiloparsec scales, indicating that the spin axis of the inner accretion disk and black hole has remained unchanged for at least one million and more likely, ten million years. This suggests that a single merger event may be responsible for the supply of gas in the nucleus of NGC 4261. The jet opening angle is between 0.3 and 20 degrees during the first 0.2 parsecs of the jet, and must be less than 5 degrees during the first 0.8 parsecs.

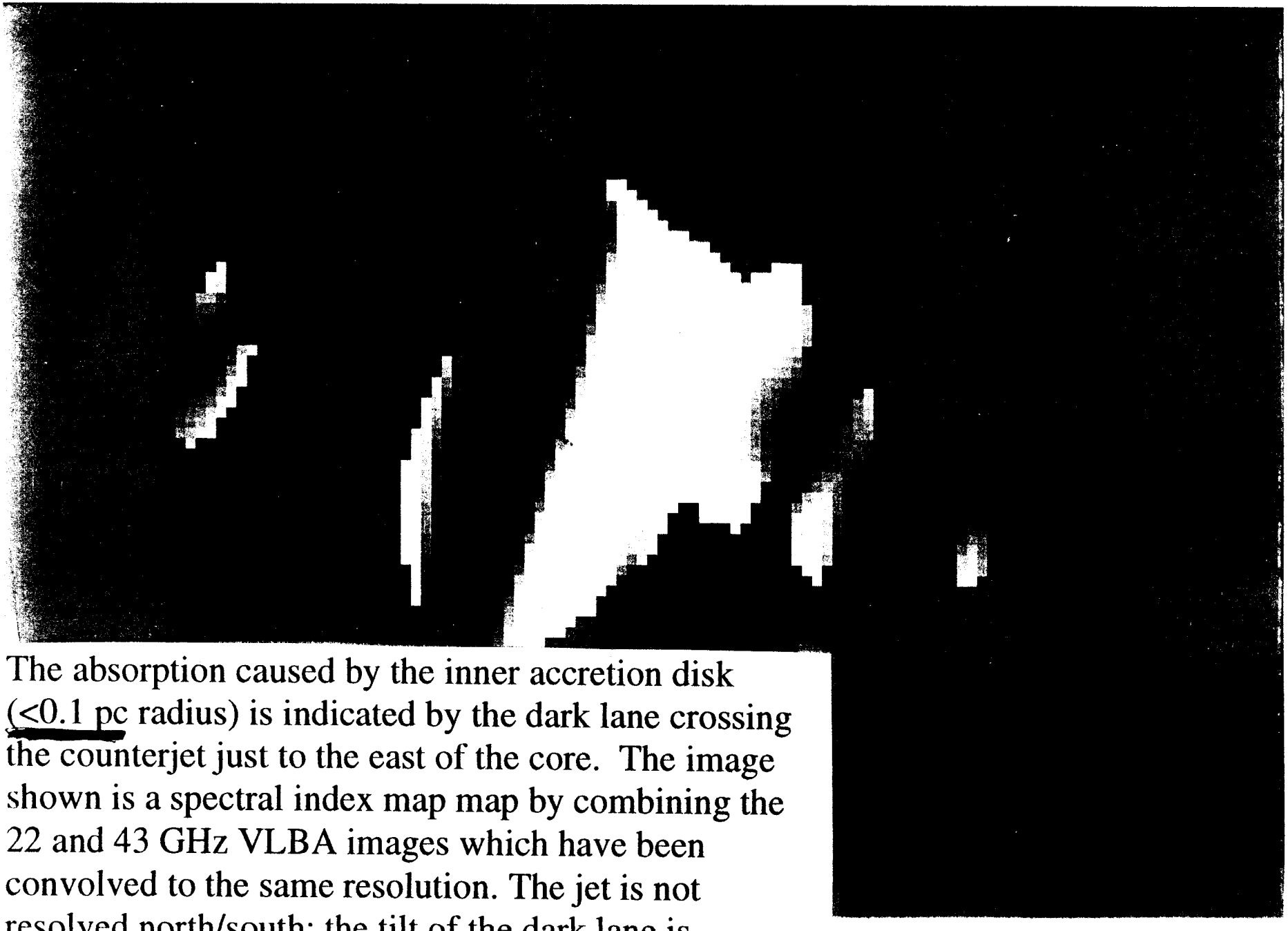
We formed a spectral index map by convolving our 43 GHz clean components with the 22 GHz beam, to match resolution. The VLBA has enough short spacings to enable this technique, after checking the flux densities as a function of uv-distance. The increased opacity due to absorption by the accretion disk is visible as a significant change in the spectral index to the east of the core.



The 43 GHz VLBA image convolved with the 22



The 22 GHz VLBA image



The absorption caused by the inner accretion disk (<0.1 pc radius) is indicated by the dark lane crossing the counterjet just to the east of the core. The image shown is a spectral index map map by combining the 22 and 43 GHz VLBA images which have been convolved to the same resolution. The jet is not resolved north/south; the tilt of the dark lane is caused by the beam. The scale is 0.1 mas = 0.02 pc.

Physical Characteristics of the Inner Accretion Disk

Assuming that the accretion disk is geometrically and optically thin and composed of a uniform 10,000 K plasma, and using the HST-measured central black hole mass of 5 x 10^8 solar masses,

- The disk thickness is 0.01 pc, the radius is 0.1 pc.
- The orbital period is about 100 years at 0.1 pc radius.
- The average electron density in the inner 0.1 pc of the disk is 10^3-10^8 cm $^{-3}$.
- The mass of ionized gas in the inner parsec of the disk is 10-1000 solar masses.
- Lifetime of the radio source is ten thousand to one million years, from accretion of the disk mass.
- The disk magnetic field is 10^{-4} – 10^{-2} gauss at 0.1 pc, if we equate the thermal gas pressure and magnetic field strength.